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PATENT SPECIFICATION

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(54) ELECTRON-BEAM APPARATUS

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33, Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particulraly described in and by the following statement:—

The invention relates to an electron beam apparatus provided with an electron source with a cathode in the form of a straight wire, and having a free end upon the tip of which impinges a beam of an auxiliary radiation source.

An electron beam apparatus of this kind is known, for example, from German Patent Specification 1,028,244. The cathode used therein consists of a tungsten wire having a diameter of from 100 to 200 microns, the end of which is heated by an ion beam. The ion beam is directed onto the wire tip by an electric field which is formed between an ion source having a positive potential with respect to the cathode tip and an electrode which is arranged opposite to the cathode tip and which has a negative potential with respect thereto. The maximum thermal electron emission which can be delivered by a cathode of this kind is determined by the material, the geometry and the temperature of the wire tip. If this cathode is set for a high emission current density, the temperature becomes very high, thus causing a comparatively large evaporation of the cathode tip. Therefore, the cathode wire can each time be advanced after a given period of operation. The evaporated material, however, will substantially contaminate the interior of the apparatus and the intermittent advancing of the wire will cause variations in the emission current.

According to the present invention an electron-beam source comprises a cathode in the form of a straight wire having a free end, an anode positioned adjacent said free end and having an aperture for forming a beam aligned with the longitudinal axis of the wire from electrons emitted from the tip of the free end of the wire, means for applying to said anode a positive voltage relative to the cathode, and an auxiliary radiation source positioned to focus radiation on the tip and to heat it to a temperature at which deformation of the tip occurs due to the electrical field strength at the tip, together with means for supporting the cathode wire and for slowly advancing it in a direction along its longitudinal axis in accordance with the evaporation rate of the tip so as to maintain the tip in substantially the same position and so as to maintain the tip in a substantially point-like shape with a substantially constant radius of curvature of between 0.2 and 2 microns.

By using a cathode wire having a thickness of approximately 10 microns to 30 microns and by heating this wire, preferably by means of a laser beam, on one free end and by displacing the cathode wire in the laser beam during operation, a wire tip having a curvature radius of the desired dimension can be maintained by suitable choice of the electric field strength at the surface of the cathode tip. The evaporation of the wire can remain within admissible limits by a suitable choice of the wire thickness and the method of heating the wire tip.

The very high current density in a point source according to the invention is feasible in that therein the requirements are satisfied for the so-termed temperature-field emission produced by the Schottky effect. Due to this effect, occurring in the case of a sufficiently high field strength on the surface and a sufficiently high temperature of the cathode material, the electrons need neither overcome the entire exit potential (work function), such as is necessary in the case of thermal emission, nor to tunnel the potential barrier as is necessary in the case of field emission. The exit potential to be overcome is substantially reduced by the applied electric field, with the result that at the same temperature the emission can be higher per unit of surface area.

A striking and very favourable side-effect of the operation at a temperature just below the melting point of the cathode material is that

the electron emission is thus rendered completely independent of the crystal direction. Because at a less high temperature the emission density is substantially lower in the wire direction than in the directions transverse thereto, an additional gain is obtained for the beam current.

Some embodiments according to the invention will be described in detail hereinafter with reference to the drawing.

Figure 1 is a diagrammatic representation of a scanning electron microscope,

Figure 2 is a diagrammatic view of an embodiment comprising a laser as controllable auxiliary radiation source, and

Figure 3 shows an embodiment for transporting and holding the cathode wire.

The scanning electron microscope which is diagrammatically shown in Figure 1 comprises a cathode in the form of a straight wire 2 which is mounted in a holder 1, a first anode 3 and a second anode 4. A free end or tip 5 of the cathode 2 is heated by a beam 6 which is generated in an auxiliary radiation source 8. In this embodiment, the auxiliary radiation source is constructed as a laser of which a beam in the infrared, visible or ultraviolet wavelength range is incident on the cathode tip 5 *via* a window (not shown) which is adapted to the wavelength of the radiation and an opening 9 in the first anode 3. Through apertures 10 and 11 in the first anode 3 and the second anode 4 respectively, passes an electron beam and through a further opening and window (not shown), preferably arranged on the side of the laser beam, the tip of the cathode can be observed, if desired. The energy incident upon to the tip of the cathode from source 6 is controlled by means of a control device 12.

The following parts of the scanning electron microscope are also shown: a condensor lens 14, a deflection unit 15, an objective lens 16, an object or specimen 17, and detectors 18 and 19. A signal which is received by one of the detectors is displayed, *via* a signal amplifier 20, on a television monitor 21 which is coupled to the deflection unit 15.

During operation, the first anode has a potential of, for example, a few thousands of volts with respect to the cathode tip. The second anode then has a potential of many thousands of volts positive with respect to the cathode tip. These potential values obviously are dependent of the geometry of the two anodes, the dimensions of the apertures in the anodes, the distance between the anodes, and the distance between the anodes and the cathode tip.

Suitably, a field strength of 10^3 to 10^5 KV/m can be generated on the surface of the cathode tip to achieve the desired emission. Because the emissive tip is also formed by the field strength, a small lateral displacement of the wire will not cause malfunctioning provided it remains within given limits.

Figure 2 is a diagrammatic representation of an arrangement for adjusting the operating conditions at the cathode. A laser beam 30, originating from a continuously radiating laser 31, is converged at the area of the tip 5, by way of a lens or lens system 32, so as to form a focal spot having a very small transverse dimension which is determined exclusively by deflection phenomena of the coherent laser radiation. In operation this heats the tip to a temperature at which deformation of the tip occurs due to the electrical field strength at the tip.

The cathode 2 is held in a clamping device which is incorporated in the holder 1 and which will be described in detail with reference to Figure 3. The clamping device serves to hold the tip 5 of the wire cathode 2 accurately in a fixed position during operation of the electron beam apparatus, and to compensate for the evaporation thereof by advancing the cathode as the tip evaporates To this end, the first anode 3 is connected to a direct voltage source 33 and through resistor 34 to the cathode. The current of anode 3 sets up a voltage across a resistor 34; this voltage is compared, by way of a direct voltage amplifier 35, with a voltage originating from a source 36. A difference signal thus obtained is integrated in an integrator 37 and provides with the aid of a current amplifier 38 an operating current for a transport mechanism of the clamping device. By means of this transport mechanism the wire cathode 2 can be slowly advanced in a direction along its longitudinal axis, for example at a speed of a few microns per minute. The tip 5, which is constantly being renewed, then tends to project into the laser beam at a constant position so that the energy it receives from the beam also tends to be constant. This adjusting mechanism caters for any slow variations in the laser intensity or the geometry of the wire tip, for example, caused by evaporation of the material.

For adjustment in the case of quicker variations, a control signal is used which is set up across a resistor 40 in series with a high voltage source 39 supplying the anode 4. *Via* a capacitor 41 and an amplifier 42, this signal controls an electrodynamic converter 12 which adjusts the position of a blade 43 which is arranged in the laser beam. Using this blade, part of the laser beam can be intercepted, with the result that the energy applied to the wire tip is reduced. The laser beam can then be constricted on one side, on more than one side, or all around.

Figure 3 shows an embodiment of a clamping device. A straight tungsten wire 2 is held between jaws 50 and 51. A resilient element 52 which at the same time serves as a hinge for the jaw 51 exerts a clamping force. The

jaws 50 and 51, the resilient element 52 and a platform 53 together constitute a clamping assembly which because of the disposition of a parallel spring system consisting of the springs 54, 55, 56 and 57, can only be displaced along the axis of the wire, that is to say along the axis of the electron beam. The platform 53 is pulled to a mounting plate 59 by a wire 58. The platform 53, and hence the cathode wire 2, is displaced by thermal length variation of the wire 58. During this displacement, a second set of jaws 59, 60 is open. At the end of a predetermined travel of the platform 53, the jaws 59, 60 close about the cathode wire, the jaws 50, 51 open, and the platform returns to a starting position so that the described process can be repeated. In a further embodiment (not shown) a coupling between the jaws prevents the two sets from being simultaneously open. This coupling can be rendered inactive for inserting a new cathode wire.

The wire 58 is heated during operation by a filament current which is supplied by the current amplifier 38 (see also Figure 2). Because the clamping faces of the jaws 50, 51 and 59, 60 are arranged to be perpendicular with respect to each other, a newly inserted cathode wire 2 will be fixed along the line of intersection of the two clamping faces after it has been advanced a few times. The opening and closing of the jaws 50, 51 and 59, 60 for transporting the cathode wire is controlled by an operating current derived, as already explained, from amplifier 38 and operable to vary the length of wires 62 and 63 by controlling heat applied to them, for example by causing this current to flow through the wires themselves.

Due to the use of a thin wire and the continuous very accurate readjustment of the cathode tip, the emission current density tends to be much higher than in known thermal electron sources of this kind, whilst the drawback of insufficient effective current of the field emission source, due to the limited dimension thereof, is at the same time overcome. It was found that, due to evaporation and surface migration, a cathode tip having a curvature radius of approximately 1 micron is maintained on the continuously advancing wire cathode. As a result, the said Schottky effect or the so-termed temperature-field emission can occur in the strong electric field at the area of the wire tip at the high temperature of the tip at which it obtains the desired dimension. A tungsten wire having a diameter of 10 microns used as the cathode wire thus produces an emission current density of the order of 10^3 A/cm^2 at a temperature of approximately 3500°K from a cathode tip having a curvature radius of approximately 1 micron which is arranged opposite to an anode which has a voltage of +2000 V with respect to the cathode tip. An electron beam can be readily separated from a source having such a high current density, the said beam being particularly suitable for use in a scanning electron microscope employing television techniques for displaying the image information.

An electron-beam source embodying the invention cannot only be used in the described scanning electron microscope, but also, for example, in a transmission electron microscope, an electron beam machining apparatus, and a microanalyzer.

WHAT WE CLAIM IS:—

1. An electron-beam source comprising a cathode in the form of a straight wire having a free end, an anode positioned adjacent said free end and having an aperture for forming a beam aligned with the longitudinal axis of the wire from electrons emitted from the tip of the free end of the wire, means for applying to said anode a positive voltage relative to the cathode, and an auxiliary radiation source positioned to focus radiation on the tip and to heat it to a temperature at which deformation of the tip occurs due to the electrical field strength at the tip, together with means for supporting the cathode wire and for slowly advancing it in a direction along its longitudinal axis in accordance with the evaporation rate of the tip so as to maintain the tip in substantially the same position and so as to maintain the tip in a substantially point-like shape with a substantially constant radius of curvature of between 0.2 and 2 microns.

2. An electron-beam source as claimed in Claim 1, characterized in that the auxiliary radiation source is formed by a continuously active laser having a radiation intensity which can be modulated by a signal derived from the beam current in the electron beam apparatus.

3. An electron-beam source as claimed in Claim 2, characterized in that the modulation signal controls an electrodynamic convertor with an intercepting screen which is movable in a direction transverse to the propagation direction of the auxiliary beam.

4. An electron-beam source as claimed in Claim 1, 2 or 3, characterized in that the wire cathode wire is held in a clamping device having two clamps which are successively arranged in the wire direction, the clamping faces thereof being arranged substantially perpendicular to each other and intersecting each other along a line which coincides with the optical axis of the electron beam apparatus, the wire cathode being displaceable by the alternating opening and closing of the clamps, controlled by a signal derived from the emission current of the wire tip.

5. An electron-beam source as claimed in Claim 4, characterized in that the clamping device comprises electrically conductive wires

which are capable of operating the clamps by way of thermal length variations which are produced by means of electrical current pulses.

6. An electron-beam source as claimed in Claim 4 or Claim 5, characterized in that a coupling between the two clamps, which can be rendered inactive for inserting a new cathode wire, prevents the clamps from being simultaneously opened.

7. An electron-beam source as claimed in any of the preceding Claims, characterized in that the cathode wire consists of a straight tungsten wire having a diameter of at the most 50 microns.

8. An electron-beam source substantially as herein described with reference to the drawings.

9. An electron-beam apparatus comprising a source as claimed in any preceding Claim.

10. An electron microscope substantially as herein described with reference to Figure 1 or Figures 1 and 2 or Figures 1 and 3 or Figures 1, 2 and 3 of the drawings.

C. A. CLARK,
Century House,
Shaftesbury Avenue,
London, W.C.2.
Agent for the Applicants.

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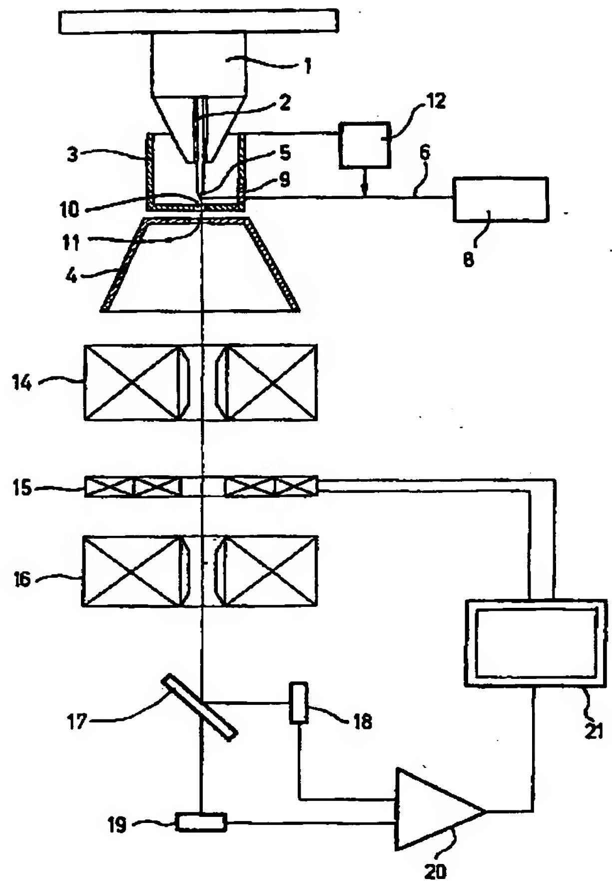

Fig. 1

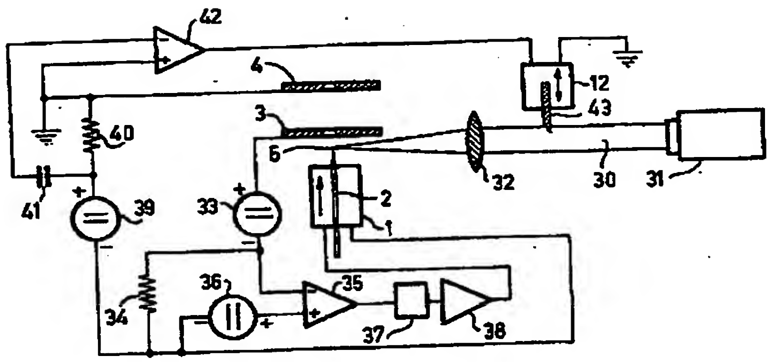
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Fig. 2

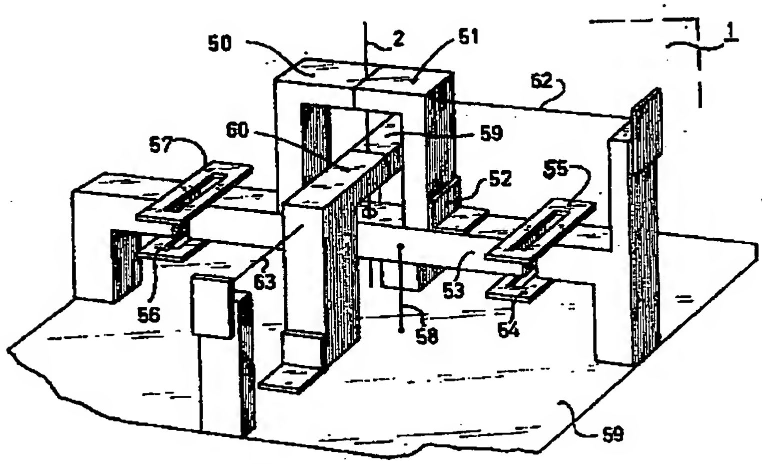
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Fig. 3